THE EFFECT OF TETRAPLOIDY ON CONTRASTING CHARACTERS IN HORDEUM VULGARE L.

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April, 1958

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ABSTRACT

1. The initial rate of development of the tetraploid forms was influenced by the malt - feed classification of the varieties. Tetraploids of malting varieties showed a slower growth when compared with the feed varieties.

2. A differential effect of tetraploidy was demonstrated with regard to the time of emergence of the flag leaf, the late varieties showing a greater percentage delay than the earlier varieties.

3. No differential effect was found to occur in the heading data, but the tetraploids were 6 - 7 days later than the diploids.

4. Reduction in number of tillers was found consistently, but the tetraploids utilized a longer growing period to better advantage. While the two row varieties had the larger number of tillers throughout, the tetraploids of the six row varieties suffered a lesser percentage reduction in number.

5. The number of ripe tillers was reduced by tetraploidy, but no differences were found in the reaction of different groupings of the varieties.

6. Length of tillers and weight of straw was reduced in the tetraploids with no differential effects occurring.

7. A greatly decreased fertility was characteristic of the autotetraploids, but the decrease was greatest in the six row varieties.

8. The six row varieties showed the greater reduction in yield.

9. The smaller seeded six row varieties showed the greater percentage increase in seed weight due to tetraploidy.

THE UNIVERSITY OF ALBERTA

THE EFFECT OF TETRAPLOIDY
ON CONTRASTING CHARACTERS IN *HORDEUM VULGARE* L.

A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

by

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EDMONTON, ALBERTA

APRIL, 1958

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INTRODUCTION

While gigantism is considered to be the major effect of polyploidy upon all organisms, many workers (Chen *et al.*, 1945; Dermen, 1940; Muntzing, 1948; Randolph, 1941; Ramanujam and Parthasarathy, 1953) have observed that the increase in size is restricted to the morphological structure of single organs rather than consistent over the whole of the organism. Although such characteristics as leaf width and thickness are increased, leaf length is often unchanged (Ekdahl, 1949). Seed weight is usually increased but a common feature of induced autopolyploids is a decided reduction in fertility and yield.

Most workers agree that autopolyploids show a slower rate of growth than corresponding diploids.

Barley, being a diploid organism, has attracted considerable attention with regard to the effects of polyploidy. In general it has been found that it behaves very similarly to other polyploids. Raw or primary tetraploids have been found to be greatly inferior to their diploids (Muntzing, 1948).

It is for these reasons that the future of tetraploid barley, and polyploid crop plants in general, is seen to lie in the production of hybrid forms in which intensive selection can be practiced (Muntzing, 1948).

Some exact information is required, however, on the original raw tetraploids so that more useful crosses can be made.

The object of this study was the examination of the effects of autotetraploidy on varieties exhibiting contrasting characteristics to determine which features of the diploid varieties could be best incorporated into a tetraploid barley breeding program.

MATERIALS AND METHODS

Twelve varieties of barley were chosen on the basis of possessing various contrasting characteristics, and the germinated seedlings were treated with colchicine.

An attempt was made initially to treat only the growing point of the coleoptile. Circles of composition board were cut out to fit inside a standard Petri dish, and holes were drilled through the board. The germinated seeds were placed upside down in the holes in such a manner that the roots would not come into contact with the colchicine solution. The Petri dish was covered to prevent evaporation.

This method proved to be long and inconvenient so the manner of treatment was changed to a simple immersion of whole seedlings into the solution. Approximately 200 seeds of each variety were germinated and then placed in a 0.5% aqueous colchicine solution for three hours. The seedlings were then rinsed thoroughly in tapwater and sown in the field.

The survival rate was exceptionally low due partly to a very dry early summer. In addition there was a great amount of bird damage later on.

The C_1 generation of plants (i.e., plants grown from the treated seeds) was harvested separately and one C_2 seed from each head was sown in a greenhouse bed. Attempts were made to detect tetraploid plants, but only three tetraploids were found, in the varieties Wolfe and Vantage.

Attempts were made to detect tetraploid plants by means of measurements of stomatal guard cells, but this method did not give clear results due to the high variability in this character.

Analysis of roottips also proved to be a poor method as the number of cells undergoing mitotic division in which the chromosomes could be counted was very low in comparison with the work required.

Selection was made on the basis of morphological characteristics and sterility. The resulting C_3 generation was then examined by Pollen Mother Cell analysis. The results were compiled in Table 1.

In addition five tetraploid varieties were obtained later. These were:

4x Golden Saitama No. 1 from Dr. Ono in Japan

4x Herta)
)
4x Gateway) from E. R. Kerber
)
4x 40 day)

4x Montcalm from S. A. Wells

In retrospect the author has concluded that the best method for detecting tetraploids in barley is a selection in the C_2 generation for morphological characteristics and sterility.

Table 1. Production and detection of tetraploids

	C_1 generation	C_2 generation			C_3 generation		
	No. of plants harvested	No. of plants PMC'd	Tetra-ploids detected	Morpho-logical selection	No. of plants PMC'd	Tetra-ploids detected	Total tetraploids found
Wolfe	32	3	2	24	17	4	6
Vantage	17	4	1	7	7	4	5
O.A.C. 21	25	2		6	5	3	3
Sanalta	9	9		1	1	1	1
Jet	12	2		1	2	1	1
Gateway	2			2	2		
Montcalm	45	14		88	69		
Newal	10	3		4	7		
Olli	7	1					
Compana	1	1					
Ackerman							
Olympia							
	160	39	3	133	110	13	16

Final confirmation can then be made by Pollen Mother Cell analysis in the C_3 generation.

Tetraploids cannot be selected in the C_1 generation because of the frequent occurrence of chimeras of tetraploid tissue. PMC selections cannot be made profitably on the C_2 generation because of the large numbers of analyses required when tetraploids are of low incidence in the treated material.

The varieties and their characteristics are listed below in Table 1a.

Table 1a. Varieties and contrasting characteristics

Variety	Use	Rows	Straw	Maturity	Yield	Awn
Wolfe	Feed	6	Strong	E - M	Low	Smooth
Vantage	Feed	6	Strong	Late	High	Smooth
O.A.C. 21	Malt	6	Medium	Medium	High	Rough
Sanalta	Feed	2	Medium	Late	High	Smooth
Jet	Feed	2		Medium	Low	Rough
Gateway	Malt	6	Medium	Early	Low	Smooth
Montcalm	Malt	6	Medium	M - L	High	Smooth
Newal	Feed	6	M - S	M - L	High	Smooth
Olli	Malt	6	Medium	Early	Low	Rough
Compana	Feed	6	Weak	E - M	High	Smooth
Ackermans	Malt	2				
Olympia	Feed	6	Medium	Late		Rough
Herta	Malt	2	Strong	M - L	High	Rough
Golden Saitama	Feed	2		Late	Low	Rough
40 Day	Feed	6		Early	Low	Rough

The Experimental Design

The experiment was set up to enable comparisons to be made between diploids and tetraploids of the varieties exhibiting contrasting characteristics. It was necessary to use a design which would accommodate the ten available varieties and their tetraploids. As it was believed that there might be considerable inter block differences due to greenhouse conditions, a 4 x 5 Rectangular Lattice was chosen, having three replications and two repetitions. Each plot was represented by one ~~plot.~~ PLANT.

This type of design is intended primarily for the reduction of inter block variation by the use of correction factors. After several analyses were completed it was found that the inter block effects were negligible. Consequently it was decided to gain additional information by changing the analysis to a factorial design.

It can then be designated as a 2 x 10 Factorial in which only the first order interaction can be included.

The form of analysis was as follows:

	DF
Replicates	5
Ploidy	1
Varieties	9
Ploidy x Varieties	9
Error	95
Total	119

RESULTS AND OBSERVATIONS

Data were accumulated on sixteen different characteristics of the plants during growth and when they were harvested. The first seven sets of data were studied as a group to provide a measure of the rate of development of the tetraploid material in comparison with the diploid progenitors.

It was assumed at the commencement of the study that the development of the diploid barley varieties would correspond closely with the agronomic classification of the varieties into early, medium and late.

The varieties 40 Day, Gateway and Wolfe were classed as Early. O.A.C. 21, Jet, Vantage and Montcalm as Medium, and Sanalta, Herta and Golden Saitama as Late.

Table 2. Mean number of days required for seedling emergence

	2x mean	4x mean	Difference
Malting varieties			
Wolfe	11.6	13.7	2.1
Montcalm	12.1	13.7	1.6
Gateway	11.7	13.2	1.5
Herta	11.9	13.4	1.5
O.A.C. 21	11.8	12.7	0.9
Group means	11.8	13.3	
Feed varieties			
Sanalta	11.3	12.1	0.8
40 Day	10.7	10.7	0
Golden Saitama	13.1	13.0	-0.1
Vantage	11.7	11.5	-0.2
Jet	12.7	11.5	-1.2
Group means	11.9	11.8	
Ploidy means	11.9	12.5	

LSD (P x V) = 0.90

Analysis of Variance

	DF	MS
Ploidy	1	14.01
Variety	9	6.22
P x V	9	3.25**
Error	95	0.61

Seedling Emergence

In Table 2 only small differences were found in the time required for seedling emergence, either among varieties or between diploids and tetraploids. The interaction, however, was significant, indicating a strong differential effect. It could be seen from the difference column that the malting group of varieties showed a significantly greater delay due to the doubling of the chromosome number than did the feed varieties. The tetraploids of the malting varieties required 12% more time to emerge than their diploids, while in the feed varieties emergence was nearly simultaneous.

Table 3. Mean number of days required for the appearance of the fourth leaf

	2x mean	4x mean	Difference
Malting varieties			
Wolfe	29.0	34.2	5.2
Herta	30.2	33.3	3.1
Montcalm	30.7	33.7	3.0
O.A.C. 21	30.3	33.3	3.0
Gateway	29.3	32.0	2.7
Group means	29.9	33.3	
Feed varieties			
Sanalta	30.2	33.0	2.8
Vantage	29.8	31.5	1.7
Golden Saitama	31.2	31.8	0.6
40 Day	30.7	31.2	0.5
Jet	32.0	32.2	0.2
Group means	30.8	31.9	
Ploidy means	30.3	32.6	

LSD (P x V) = 1.29

Analysis of Variance

	DF	MS
Ploidy	1	156.41**
Varieties	9	3.59
P x V	9	7.08**
Error	95	1.27

Fourth Leaf Stage

It can be seen from Table 3 that the tetraploid forms were significantly later as a group than the diploids, by about 2 days, while there was apparently no real difference between variety means.

Again, however, the tetraploids of the malting varieties required a longer time to reach this stage, (110% of the malting diploids), than did the tetraploids of the feed varieties which required only 106% of the time for their corresponding diploids.

Table 4. Mean number of days required for the production of the second tiller

	2x mean	4x mean	Difference
Vantage	32.0	35.7	3.7
Gateway	32.8	34.7	1.9
Jet	33.0	34.2	1.2
Montcalm	31.5	34.3	2.8
O.A.C. 21	31.0	33.7	2.7
Golden Saitama	31.2	33.0	1.8
Sanalta	31.2	32.7	1.5
Wolfe	29.8	33.7	3.9
Herta	29.3	31.7	2.4
40 Day	29.3	31.2	1.9
Means	31.1	33.5	

Analysis of Variance

	DF	MS
Ploidy	1	165.68**
Varieties	9	19.23**
P x V	9	2.40
Error	95	2.01

Second Tiller Stage

The second tiller was formed at about the same time as the fourth leaf. From Table 4 it can be seen that the tetraploids were 2.5 days later than the diploids and that there was apparently no differential effect of tetraploidy upon this character. The variety means were significantly different but these differences were small and not closely associated with any of the factors under study.

There was, however, a significant negative correlation ($r = -0.703^{*}$) between the mean days required for the second tiller and the mean number of tillers at 54 days, when only the diploids were considered. This indicated that early tillering depended to some extent on the rapidity with which the second tiller appeared. This relationship, however, did not extend to the total number of tillers or the number of ripe tillers produced in each variety.

Table 5. Mean number of days required for the production of the third tiller

	2x mean	4x mean	Difference
Malting varieties			
Gateway	36.2	44.6	8.4
Herta	31.3	39.5	8.2
Wolfe	31.3	38.3	7.0
Montcalm	35.8	41.6	5.8
O.A.C. 21	35.0	38.8	3.8
Group means	33.9	40.6	
Feed varieties			
Golden Saitama	33.5	37.8	4.3
Vantage	35.2	39.3	4.1
Sanalta	32.8	35.8	3.0
40 Day	32.2	35.0	2.8
Jet	37.0	37.0	0
Group means	34.1	37.0	
Ploidy means	34.0	38.8	

LSD (P x V) = 3.11

Analysis of Variance

	DF	MS
Ploidy	1	681.64**
Varieties	9	52.22
P x V	9	20.87**
Error	95	7.41

Third Tiller Stage

The third tiller of the diploids emerged three days after the second, while in the tetraploids it was five days later. Although the tetraploids were in general five days later than the diploids, there was no significant variation among the variety means.

The malting varieties again suffered a greater delay in reaching this stage than the feed varieties, requiring a 19% increase in number of days over their diploids, as opposed to a 10% increase in the feed group.

Table 6. Mean number of days required for the appearance of the fifth leaf

	2x mean	4x mean	Difference
Malting varieties			
Wolfe	33.3	39.3	6.0
Herta	34.7	40.0	5.3
Gateway	33.5	38.0	4.5
O.A.C. 21	34.8	39.3	4.5
Montcalm	35.3	39.7	4.4
Group means	34.3	39.3	
Feed varieties			
Sanalta	33.8	39.0	5.2
Vantage	34.7	37.3	2.6
Jet	37.7	39.5	1.8
Golden Saitama	36.5	38.3	1.8
40 Day	36.5	38.0	1.5
Group means	35.8	38.4	
Ploidy means	35.1	38.8	

LSD (P x V) = 1.79

Analysis of Variance

	DF	MS
Ploidy	1	425.64**
Variety	9	8.60
P x V	9	8.21**
Error	95	2.41

Fifth Leaf Stage

It was seen from Table 6 that the malting varieties were again delayed in reaching this stage, requiring 114% of the time needed by their diploids, as opposed to 109% for the tetraploids of the feed varieties. As a group the tetraploids again demonstrated a lag of four days.

Table 7. Mean number of days required for the appearance of the flag leaf

	2x mean	4x mean	Difference
Late varieties			
Golden Saitama	79.3	81.3	2.0
Sanalta	77.0	81.6	4.6
Herta	76.6	80.6	4.0
Group means	77.6	81.2	
Medium varieties			
Jet	75.6	77.3	1.7
Montcalm	74.3	76.5	2.2
O.A.C. 21	74.0	77.0	3.0
Vantage	72.5	75.0	2.5
Group means	74.1	76.4	
Early varieties			
Wolfe	72.6	74.1	1.5
40 Day	71.3	71.0	-0.3
Gateway	64.1	63.0	-1.1
Group means	69.3	69.4	
Ploidy means	73.7	75.7	

LSD (P x V) = 2.04

Analysis of Variance

	DF	MS
Ploidy	1	120.20**
Varieties	9	282.56**
P x V	9	9.43**
Error	95	3.18

Flag Leaf Stage

Tetraploidy again caused a significant delay averaging 2 days over all varieties. Diploid and tetraploid means all fall into order according to maturity, indicating that there was no unexpected reaction to tetraploidy at this stage. When the data on the differential effects were examined it was found that a greater number of days was required in the late tetraploids than among the early tetraploids. It was found that late tetraploids required 105%, the medium tetraploids 103% and the early tetraploids 100% of the time required for their respective diploids to reach the same stage.

Golden Saitama was significantly less delayed than the other two late varieties. There were no differences among the medium group, but the variety Gateway was significantly different from Wolfe, indeed being accelerated by the induced tetraploidy.

Table 8. Mean number of days required for heading

	2x mean	4x mean	Difference
Late varieties			
Golden Saitama	90.6	97.1	6.5
Herta	87.0	94.5	7.5
Sanalta	86.3	94.5	8.2
Group means	88.0	95.4	
Medium varieties			
Jet	82.5	89.0	6.5
Vantage	82.1	88.1	6.0
O.A.C. 21	81.3	88.1	6.8
Montcalm	82.0	86.8	4.8
Group means	82.0	88.0	
Early varieties			
40 Day	80.1	86.1	6.0
Wolfe	79.5	86.5	7.0
Gateway	75.1	78.8	3.7
Group means	78.2	83.8	
Ploidy means	82.6	89.0	

Analysis of Variance

	DF	MS
Ploidy	1	1190.70**
Varieties	9	276.43**
P x V	9	5.01
Error	95	9.49

Heading Stage

This analysis was complicated by several cases of missing data. The criterion used for "Heading-out" was the emergence of the base of the spike from the top of the boot. Several plants ripened before this standard was achieved and it was, of course, then too late to alter the measurement used.

The tetraploids were later than the diploids by about six days. No differential effect of tetraploidy was apparent and the agronomic grouping into maturity classes was followed by all varieties, no exceptions being noticed.

Using the variety means it could be seen that Gateway differed significantly from Wolfe, 40 Day and the medium group of varieties. The late group differed from all the others.

Table 9. Mean number of tillers at 54 days

	2x mean	4x mean	Difference
Two row varieties			
Herta	15.2	7.0	8.2
Sanalta	12.5	7.8	4.7
Golden Saitama	12.2	6.8	5.4
Jet	7.7	6.0	1.7
Group means	11.9	6.9	
Six row varieties			
40 Day	11.0	7.8	3.2
Wolfe	10.8	4.7	6.1
Vantage	8.8	4.0	4.8
O.A.C. 21	7.8	4.8	3.0
Gateway	7.5	4.3	3.2
Montcalm	7.5	3.0	3.7
Group means	8.9	4.8	
Ploidy means	10.1	5.7	

LSD (P x V) = 1.65

Analysis of Variance

	DF	MS
Ploidy	1	576.42**
Varieties	9	46.49*
P x V	9	10.48**
Error	95	2.06

Number of Tillers at 54 Days

From Table 9 the diploids of the two row varieties in general were found to exceed the six row varieties in number of tillers. While tillering in the tetraploids was reduced to half that of the diploids, the two row varieties again exceeded the six row group, but by a slightly larger percentage, (44% vs. 34% in the diploids).

While the interaction was significant, supporting the above observations, little information was really obtained as it merely gave a measure of the differences between the varieties Herta and Jet.

Herta is noted for its high degree of tillering while Jet is usually low. Forty Day was also unusually high in tillering and appeared to respond well to tetraploidy.

Table 10. Mean number of tillers at 150 days

	2x mean	4x mean	Difference
Two row varieties			
Herta	23.7	15.3	8.4
Jet	16.8	21.2	-4.4
Sanalta	17.8	9.3	8.5
Golden Saitama	15.3	10.0	5.3
Group means	18.4	14.0	
Six row varieties			
40 Day	13.8	14.8	-1.0
Montcalm	14.2	12.0	2.2
O.A.C. 21	14.0	9.3	4.7
Gateway	12.7	9.7	3.0
Vantage	12.5	8.3	4.2
Wolfe	10.3	8.0	2.3
Group means	12.9	10.4	
Ploidy means	15.1	11.8	

Analysis of Variance

	DF	MS
Ploidy	1	330.01**
Variety	9	139.86**
P x V	9	46.06
Error	95	28.27

Number of Tillers at 150 Days

From Table 10 the two row varieties possessed larger numbers of tillers than the six row group in both the diploid and tetraploid forms. In addition it was found that, with the exception of Jet, the two row varieties were most adversely affected by tetraploidy, but the difference was not significant in the analysis of variance.

When these data were compared with that on the number of tillers at 54 days (Table 9), it was apparent that the tetraploids had doubled the number of tillers in the latter part of the growing season while the diploids showed an increase of only half.

Table 11. Mean number of ripe tillers

	2x mean	4x mean	Difference
Two row varieties			
Herta	18.8	5.8	13.0
Sanalta	12.2	6.5	5.7
Golden Saitama	10.0	5.5	4.5
Jet	12.3	8.8	3.5
Group means	13.3	6.6	
Six row varieties			
40 Day	11.3	7.5	3.8
O.A.C. 21	8.8	4.5	4.3
Gateway	8.7	4.5	4.2
Wolfe	8.5	4.7	3.8
Vantage	8.3	4.2	4.1
Montcalm	7.0	4.2	2.8
Group means	8.8	4.9	
Ploidy means	10.6	5.6	

LSD (P x V) = 3.35

Analysis of Variance

	DF	MS
Ploidy	1	745.01**
Variety	9	58.50
P x V	9	25.40**
Error	95	8.55

Number of Ripe Tillers

Tetraploidy reduced the number of ripe tillers by half in both the two row and the six row groups of varieties. Although the two row varieties possessed a large number of tillers generally and the interaction was significant in the analysis of variance, there was no differential effect due to tetraploidy. Only the variety Herta differed from the others in its response to tetraploidy.

Table 12. Mean height of the highest tiller (inches)

	2x mean	4x mean	Difference
Tall straw			
O.A.C. 21	51.5	41.0	10.5
Montcalm	48.6	39.0	9.6
Sanalta	45.8	39.0	6.8
Group means	48.6	39.7	
Medium straw			
Vantage	47.6	35.8	11.8
Golden Saitama	44.6	33.0	11.6
Herta	44.0	32.8	11.2
Gateway	43.0	36.3	6.7
Group means	44.8	34.5	
Short straw			
Wolfe	40.8	36.3	4.5
Jet	40.7	35.5	5.2
40 Day	39.3	34.7	4.6
Group means	40.3	35.5	
Ploidy means	44.6	36.3	

Analysis of Variance

	DF	MS
Ploidy	1	2050.07**
Variety	9	105.31**
P x V	9	27.01
Error	95	14.77

Table 13. Mean height of the ripe tillers (inches)

	2x mean	4x mean	Difference
Tall straw			
O.A.C. 21	46.0	38.2	7.8
Montcalm	45.8	37.0	8.8
Sanalta	40.8	34.3	6.5
Group means	44.2	36.5	
Medium straw			
Vantage	43.5	32.5	11.0
Golden Saitama	39.7	30.0	9.7
Gateway	38.5	32.0	6.5
Herta	37.0	29.7	7.3
Group means	39.7	31.0	
Short straw			
Wolfe	38.0	32.7	5.3
40 Day	35.7	32.0	3.7
Jet	33.7	30.8	2.9
Group means	35.8	31.8	
Ploidy means	39.9	32.9	

Analysis of Variance

	DF	MS
Ploidy	1	1449.07**
Variety	9	132.74**
P x V	9	19.67
Error	95	15.16

Table 14. Mean dry weights of straw (grams)

	2x mean	4x mean	Difference
Tall straw			
O.A.C. 21	25.5	17.1	8.4
Montcalm	23.6	18.1	5.5
Sanalta	22.5	16.8	5.7
Group means	23.9	17.3	
Medium straw			
Herta	25.3	11.7	13.6
Vantage	23.4	15.4	8.0
Gateway	22.0	15.0	7.0
Golden Saitama	20.8	17.0	3.8
Group means	22.9	14.8	
Short straw			
Wolfe	19.9	12.8	7.1
40 Day	15.2	14.5	0.7
Jet	15.1	20.6	-5.5
Group means	16.7	16.0	
Ploidy means	21.3	15.9	

Analysis of Variance

	DF	MS
Ploidy	1	884.00**
Variety	9	45.46
P x V	9	76.84
Error	95	43.04

Straw Characteristics

The tetraploids showed decreases in both the height of the heighest tiller (Table 12) and in the average height of the ripe tillers (Table 13), possessing 81% and 82% respectively of the tiller heights of their diploids.

There was apparently no differential effect of tetraploidy upon tiller heights. The agronomic classification of the varieties into height classes was followed reasonably closely.

Straw weight was measured as the weight of the plant, air dried, with the spikes removed and all soil removed from the roots. From Table 14 it was found that tetraploidy effected a reduction in straw weight to 75% of that in the diploids. There were no significant variety or differential effects.

	Transformed data				Percentage data		
	2x mean	4x mean	Difference		2x mean	4x mean	Difference
Six row varieties							
40 Day	79.1	31.3	47.8		96.4	27.0	69.4
Montcalm	60.5	15.3	45.2		75.7	7.0	68.7
Vantage	74.6	32.3	42.3		93.0	28.5	64.5
Gateway	68.5	33.5	35.0		86.6	30.5	56.1
O.A.C. 21	76.5	41.5	35.0		94.5	43.9	50.6
Wolfe	64.3	38.5	25.8		81.2	38.7	42.5
				Group means	87.9	29.3	
Two row varieties							
Herta	75.8	43.0	32.8		94.0	46.5	47.5
Golden Saitama	75.0	50.6	24.4		93.3	59.7	33.6
Jet	75.6	54.3	21.3		93.8	66.0	27.8
Sanalta	74.6	60.3	14.3		93.0	75.5	17.5
				Group means	93.5	61.9	
	72.4	40.1		Ploidy means	90.2	42.3	

Analysis of Variance

	DF	MS
Ploidy	1	31492.77**
Variety	9	879.52
P x V	9	356.88**
Error	95	54.55

LSD (P x V) = 8.45

Percentage Fertility

The data presented in Table 15 were analysed after being transformed by the angular transformation Angle = arc sin $\sqrt{\text{percentage}}$. The analysis of variance was applied to the transformed data, but the inferences were made in terms of percentage data restored to the original scale.

Fertility was cut to half the diploid average by tetraploidy. This reduction was found to be greatest in the six row varieties. The six row group was reduced to a third of the diploid fertility, while the two row varieties were reduced to two-thirds of their diploids. Thus, as tetraploids, the two row group had twice the fertility of the six row varieties.

The lower degree of fertility in the diploid six row varieties Montcalm, Gateway and Wolfe was not accounted for. The Montcalm seed used was obtained from field grown material. The varieties Gateway and Wolfe are relatively recent and some sterility in them may be due to this fact.

Fertility was measured by counting the number of kernels and florets in the central rows of florets only, so as to place two row and six row varieties on a similar basis. Every head on each plant was included in the count.

Table 16. Mean yield (grams)

	2x mean	4x mean	Difference
Two row varieties			
Jet	10.87	5.37	5.50
Golden Saitama	14.86	5.50	9.36
Sanalta	17.98	7.35	10.63
Herta	20.52	2.92	17.60
Group means	16.06	5.28	
Six row varieties			
Wolfe	18.32	4.24	14.08
O.A.C. 21	20.84	6.57	14.27
Montcalm	15.30	0.58	14.72
Gateway	18.22	3.31	14.91
40 Day	19.44	2.49	16.95
Vantage	20.84	3.34	17.50
Group means	18.83	3.42	
Ploidy means	17.69	4.17	

LSD (P x V) = 4.88

Analysis of Variance

	DF	MS
Ploidy	1	5513.09**
Variety	9	40.33
P x V	9	46.17*
Error	95	18.08

Yield

It was expected that the classification of the varieties agronomically for yield would give some valuable information. This, however, was not the case. The high yielding varieties, Vantage, Herta, O.A.C. 21, Montcalm and Sanalta showed a range of 20.8 to 15.3 grams per plant. The low yielding varieties, Wolfe, Gateway, 40 Day, Golden Saitama and Jet ranged from 19.4 to 10.9. On the average the former outyielded the latter by 17%. This difference was not enough, however, to reach significance.

It was noticed, however, that there was a differential effect of tetraploidy when the two row - six row characteristic was considered. The two row group of varieties were least affected by tetraploidy, although the variety Herta was an exception, being very much reduced in yield.

Table 17. Mean thousand kernel weight (grams)

	2x mean	4x mean	Difference
Two row varieties			
Sanalta	51.4	53.1	1.7
Jet	51.4	53.4	2.0
Herta	43.4	46.1	2.7
Golden Saitama	50.0	56.8	6.8
Group means	49.0	52.4	
Six row varieties			
O.A.C. 21	42.2	46.0	3.8
Montcalm	48.4	52.3	3.9
Gateway	42.1	49.7	7.6
Wolfe	38.3	46.8	8.5
Vantage	43.9	53.6	9.7
40 Day	34.9	56.1	21.2
Group means	41.6	50.8	
Ploidy means	44.6	51.4	

LSD (P x V) = 4.84

Analysis of Variance

	DF	MS
Ploidy	1	1381.76**
Varieties	9	184.89
P x V	9	101.70**
Error	95	17.90

Thousand Kernel Weight

It was apparent from Table 17 that the two row varieties have an inherently higher kernel weight. While tetraploidy increased the kernel size in all varieties, the two row group showed less degree of increase (7%) than did the six row varieties (22%). This statement may be confirmed by an examination of the difference column of the table. In addition there was a significant negative correlation between thousand kernel weight and the increase in weight due to tetraploidy. There was then a decided differential effect favouring the smaller seeded varieties.

PLATES I - V. A COMPARISON OF DIPLOID AND TETRAPLOID HEADS

OF BARLEY VARIETIES

Plate I

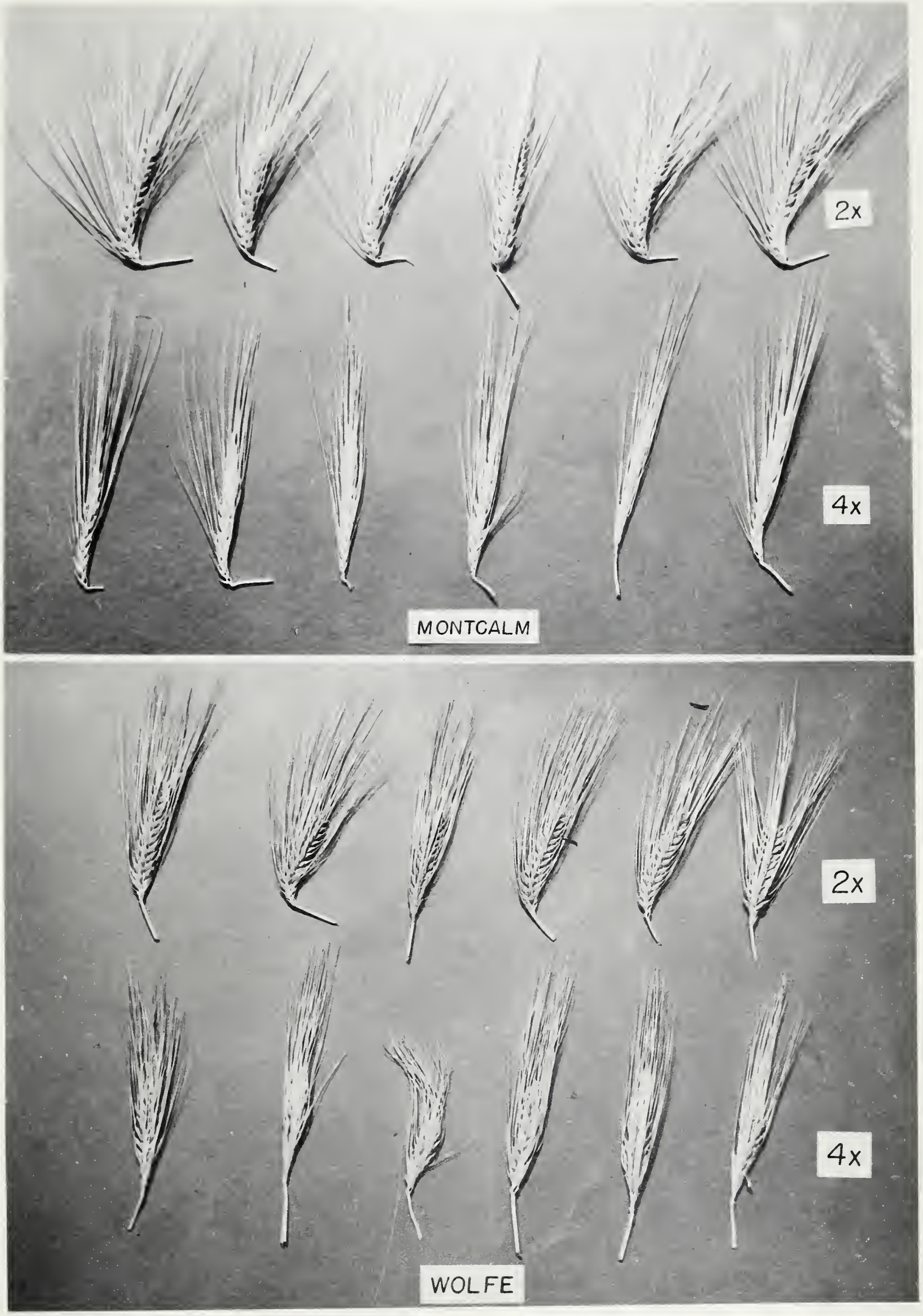

Plate II

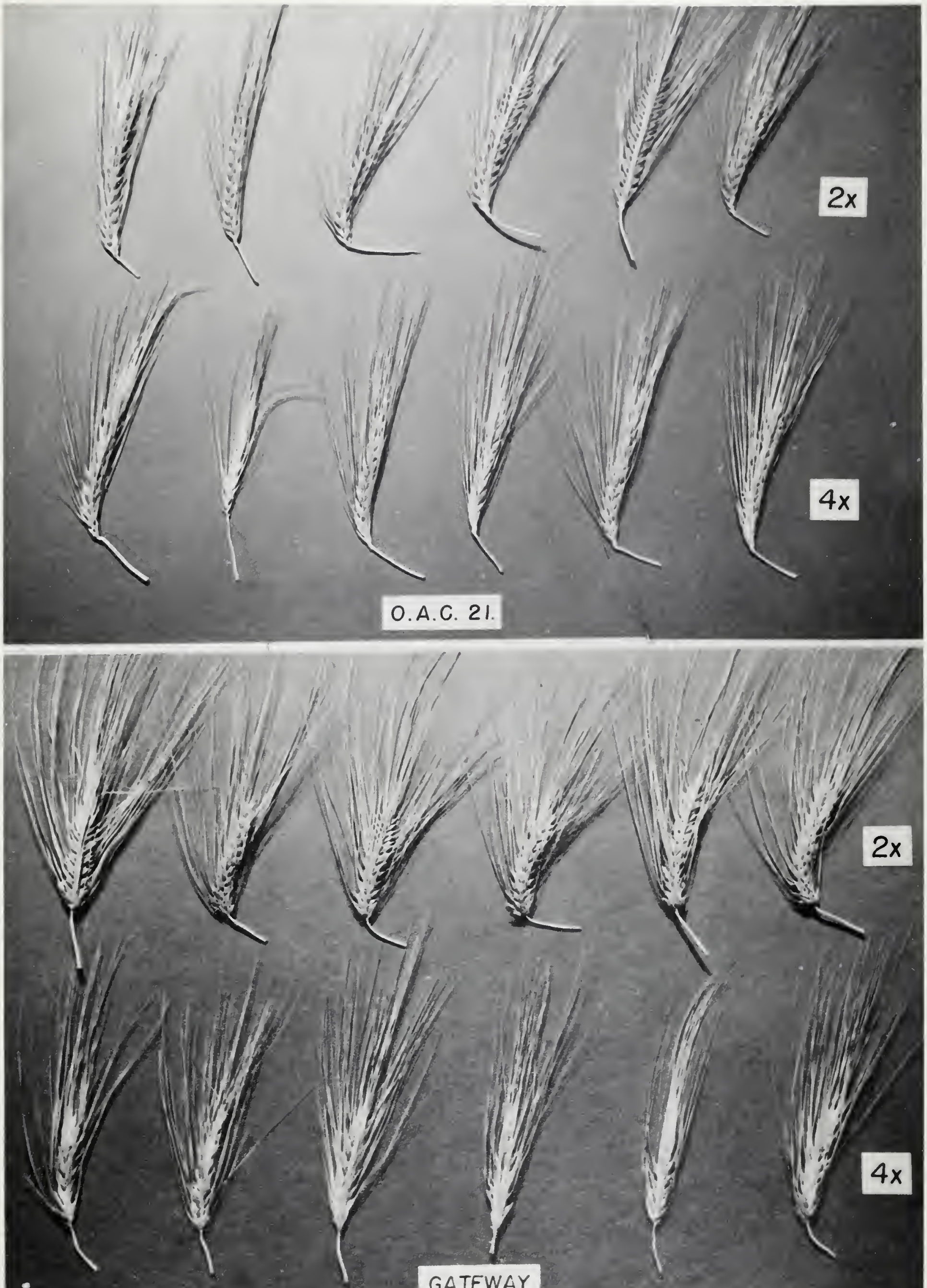

Plate III

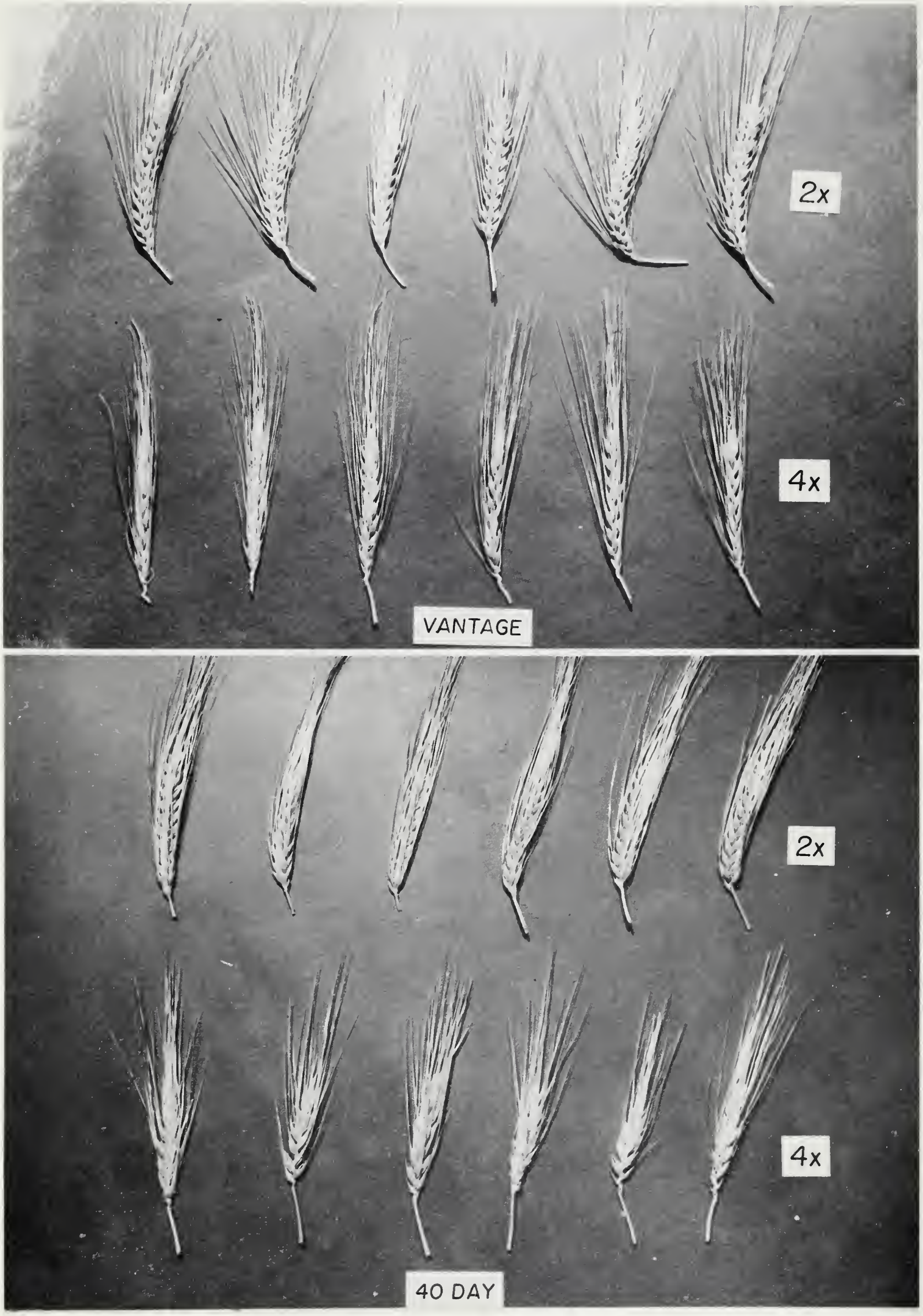

Plate IV

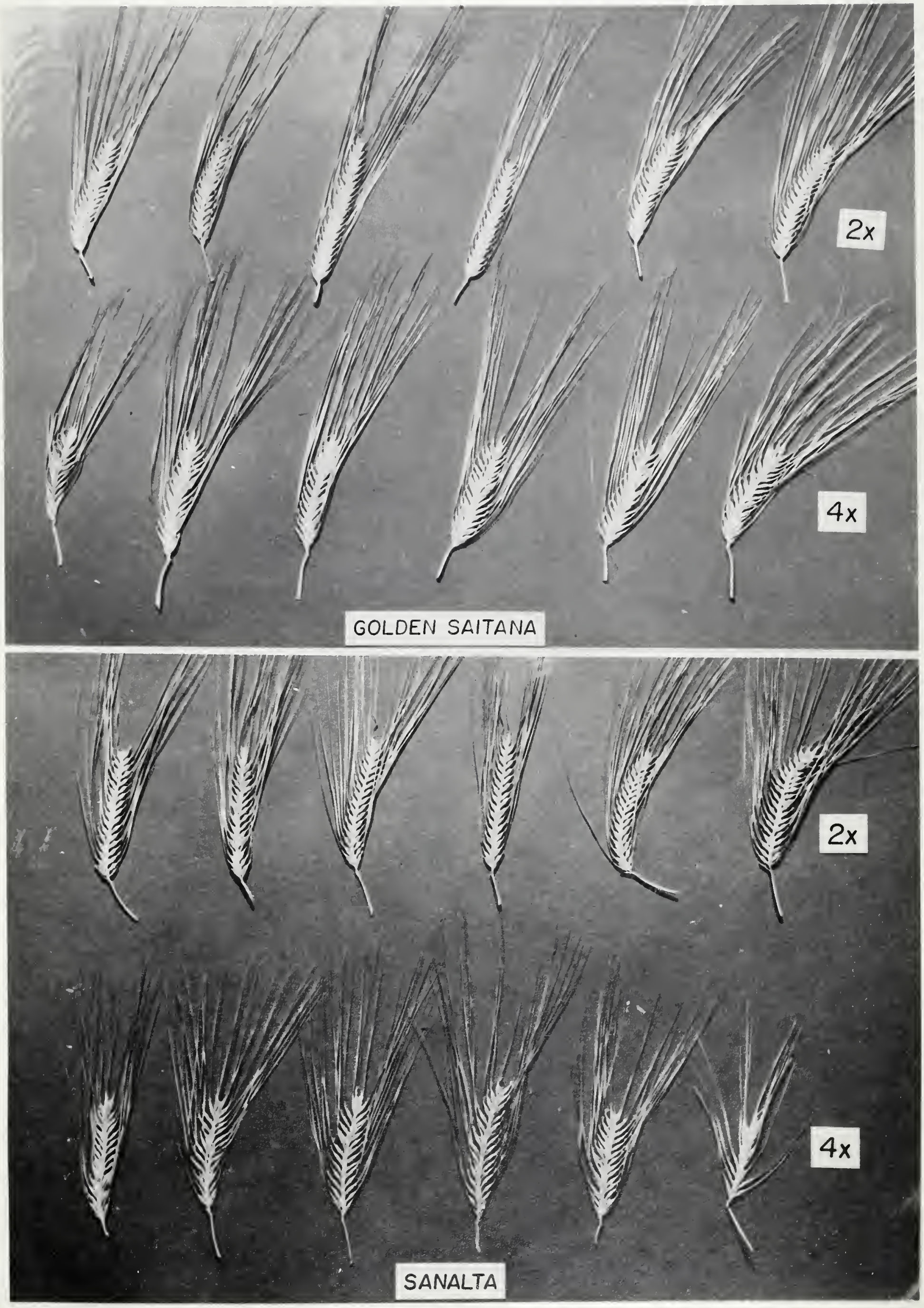

Plate V

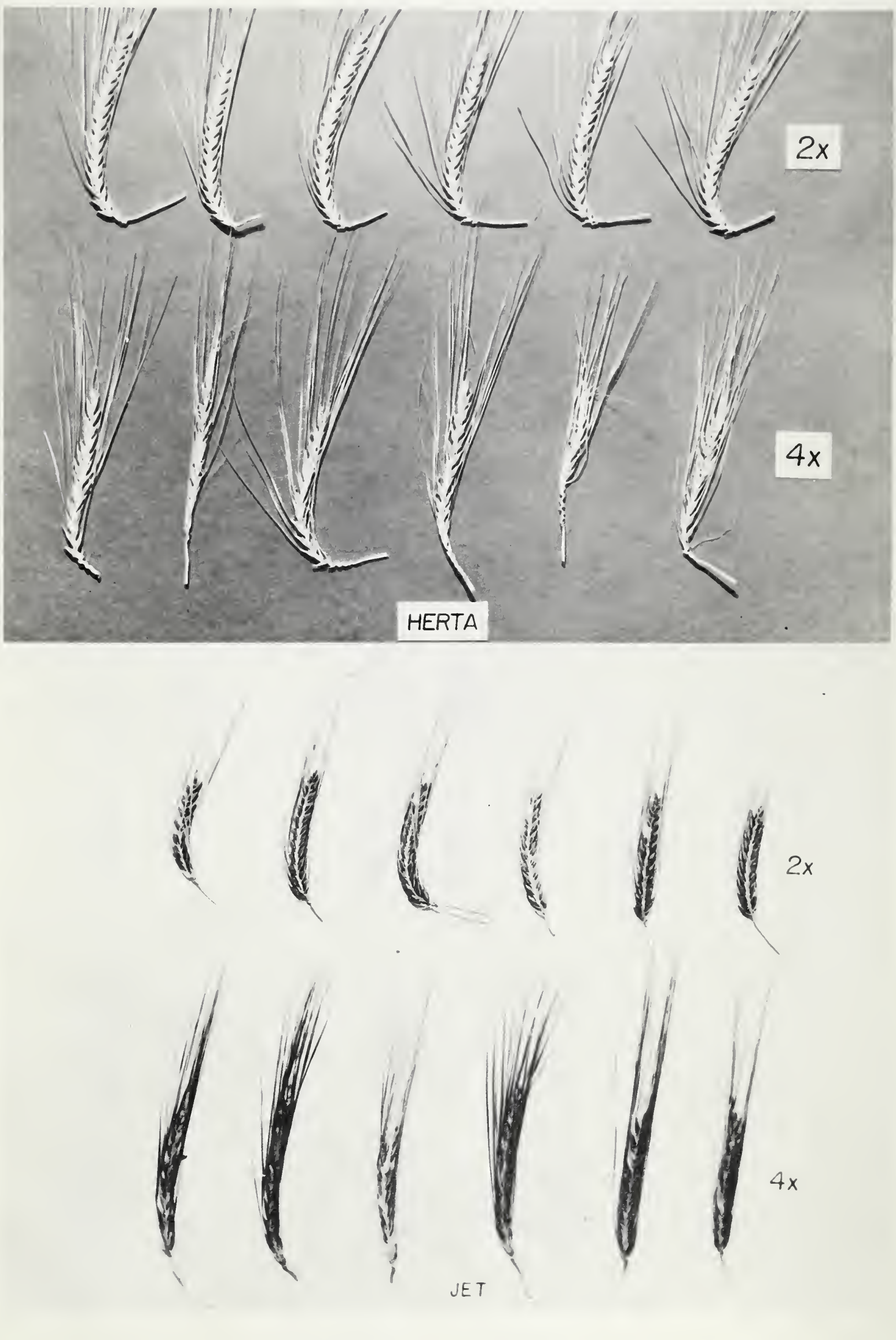

PLATE VI. TETRAPLOID (LEFT) AND DIPLOID KERNELS OF BARLEY VARIETIES

Fig. 1. Gateway
Fig. 2. O.A.C. 21
Fig. 3. Sanalta
Fig. 4. Herta
Fig. 5. Golden Saitama
Fig. 6. Jet
Fig. 7. Wolfe
Fig. 8. Montcalm
Fig. 9. 40 Day
Fig. 10. Vantage

DISCUSSION

It was determined that there were distinct differences in the response of various varieties to tetraploidy and that these differences corresponded with several groupings of the varieties according to major contrasting characteristics.

The most important factor in the early stages of the development of the plants appeared to be grouping of the varieties into the malting - feed classification. The malting varieties showed a greater delay in reaching various stages of development than did the feed barleys. This was possibly due to the lower protein content of the seed which is a feature of malting barleys. Muntzing (1948) stated that he found an increase of about 50% in protein content in tetraploid barley kernels. It was considered possible that the increase was greatest in the higher protein feed barleys. This might explain the differential that was found in the early stages of growth. The benefits derived from this initial advantage could conceivably be apparent for some time after germination of the seeds. Further work is required upon this point before any definite statement can be made.

The variety Wolfe, although not a malting barley, was included in that group. From the cross (Sanalta x Titan) x (Montcalm x Olli), this variety was originally developed for malting, but was never accepted. For the purposes of this experiment, however, Wolfe was considered to possess the characteristics of a malting barley as it reacted similarly to tetraploidy.

Differing responses to tetraploidy were not found in the data dealing with the appearance of the second tiller (the first

secondary tiller). The correlation between mean days to the appearance of the second tiller in the diploids and the mean number of tillers at 54 days, also in the diploids, ($r = -0.703^{*}$) indicated that the amount of early tillering depended upon the rapidity with which the second tiller appeared.

The delay due to tetraploidy in the time of the emergence of the flag leaf was found to depend on the agronomic classification of the varieties. With certain exceptions, the late varieties were later than their diploids by 5%, the medium group of varieties by 3%, while the early varieties were relatively unaffected.

This differential did not occur, however, at the time of heading out. All varieties were delayed an average of 6 - 7 days, with no significant differences being found. Muntzing (1948) stated that barley autotetraploids headed up to one week later than the diploids while Chen et al. (1945) found that heading was delayed by about 14 days. Levan (1942) working with tetraploid flax reported flowering was delayed 2 - 3 days.

The present material was grown in the greenhouse from the middle of winter until the early summer. In the first part of the growing period the temperature was set at 55° F. and no artificial lighting could be used. In consequence the material required an abnormally long growing period, although the plants did grow very heavily.

Normally barley varieties head at 45 - 60 days and mature at 90 - 110 days. Under the conditions of this experiment, heading required 75 - 90 days and the plants could not be harvested until 150 days.

Chen et al. (1945) stated that they found a reduction in the number of ripe tillers in the tetraploids, but no decrease in the total number of tillers. Greis (1940) quoted by Smith (1951), found an increase in the number of tillers and also an increase in the weight of straw in tetraploid barley.

The present material demonstrated a reduction in the total number of ripe tillers. When the two row and six row groups of varieties were compared it was found that the two row varieties had a larger number of tillers than the six row varieties.

In the first third of the growing period the six row varieties, in the tetraploid condition, were seen to possess only 70% of the number of tillers of the two row varieties. Among the diploids the corresponding figure was 75%.

When the plants were harvested at 150 days the situation was different. The six row tetraploids now had 74% of the tillering found in the two row tetraploids, while in the diploids the figure had decreased to 70%. This indicated that the six row varieties were better able to utilize a longer growing period when in the tetraploid condition than the two row varieties.

Another interesting relationship appeared when the increases in tillering during the latter two-thirds of the growth period were examined. While the diploids showed increases of approximately 50% during this period, the two row tetraploids increased by 103% and the six row tetraploids increased by 117% of their former tiller numbers. This showed rather clearly that a longer growing season benefitted the tetraploids much more than it did the diploid varieties.

No such differences appeared, however, in the data dealing with the number of ripe tillers, except that the variety Herta, having a large number of tillers as a diploid, showed a much greater reduction due to tetraploidy than did the others.

Ono, quoted by Smith (1951) found a reduction in stem length in barley tetraploids. The lines he tested averaged 85% of the stem lengths of their diploids.

Chen et al. (1945) reported a greater reduction, the tetraploids had only 66% of the height of their diploids. Working in flax, Levan (1942) found a reduction of only 3%.

The present data were in general agreement with the above literature, the corresponding figure being 81% when the highest tiller of each plant was compared, and 82% for the mean height of all ripe tillers.

As was mentioned previously Greis, quoted by Smith (1951), found an increase in tillering and also an increase in quantity of straw. However, several other workers have found a reduced tillering to be characteristic of tetraploid barley, so it may be presumed that the quantity of straw would be decreased also. Such proved to be the case in the author's material. The air dry straw, minus the heads, weighed 21 grams per plant in the diploid varieties, but only 16 grams in the tetraploids.

A clear difference could be seen between the responses of six row and two row varieties of barley with regard to the percentage fertility data. The tetraploids of the two row varieties showed a

much higher fertility than those of the six row group. It was considered possible that the two row barleys, having dominant genes for the character 'Two-row' (Smith, 1951), in some way suffered less harm from the doubling of their chromosome number. It was possible also that the character 'Two-row' was really a sterility factor and that this resulted in an increase in fertility in the tetraploid over the "more fertile" six row varieties. The greater supply of nutrients per floret in the two row varieties might have some effect here also.

While Muntzing (1948) found that fertility varied between years and also between lines of tetraploids, Ono found in addition that his two row lines possessed 73% and six row lines had 67% of the fertility of the corresponding diploid lines.

Plates (I, II, III, IV and V) show diploid and tetraploid heads of each variety, each head having been taken from a different plant. The overall appearance of the heads of tetraploid barley is quite visible, as is the degree of sterility.

A common feature of tetraploidy in plants was an increase in seed size. Chen (1945) found that the tetraploid seeds of barley weighed 0.04 to 0.05 grams per seed while those of the diploids weighed approximately 0.03 grams. Ono reported an increase of 38% while Muntzing (1948) states that tetraploid barley seeds are between 40% and 50% heavier. Levan (1942) in flax found the increase to be about 45%.

The average increase in size in the present material was found to be 15%. This figure was deceptively low as it included all of the seeds from the tetraploids, many of which seeds were quite underdeveloped.

A somewhat better view of the situation can be gained from Plate (VI) showing the comparative sizes of representative kernels from tetraploids and diploids.

There was, however, a greater percentage increase in kernel weight among the six row varieties (22%) than among the two row varieties (7%). Thus, although the two row varieties had the heavier kernels, the increase was greatest in the smaller seeded six row varieties. This was confirmed by a significant negative correlation ($r = -0.735^{*}$ D.F. = 8) between the 1,000 kernel weight of the diploids and the increase in weight due to tetraploidy.

It was in yield that the tetraploids proved to be most disappointing, averaging only 24% of the yield of the diploids. Muntzing (1951) stated that the yield in his material on a plot basis, was less than half that of the diploids. The two row varieties suffered less reduction in yield than the six row group but it was felt that this could be explained on the basis of increased fertility, higher kernel weight and a larger number of ripe tillers per plant.

A paper by Sakai and Suzuki (1955) on the effects of competition between diploid and tetraploid barley indicated several points of importance in the consideration of the results of the present experiment. Firstly, diploid plants surrounded by their tetraploids showed significant gains in many agronomic features when compared with diploids grown in pure stands. Secondly, tetraploid plants surrounded by diploids showed losses in the same characteristics when compared with tetraploids in pure stands.

Because the present material was fully randomized in the design, both tetraploids and diploids were freely intermixed. It was presumed that the diploids would have shown gains in most characteristics measured and the tetraploids, losses, but that these effects would not be so great as to alter the main conclusions derived from the experiment.

Conclusions derived from the present data agreed in general with those in the literature. Tetraploids of pure varieties were found to be inferior in almost all respects to their diploid progenitors. Shorter straw (with a probable increase in resistance to lodging), and larger seeds were the only characteristics which could be classed as having immediate agronomic value. A differential response to tetraploidy was found in three contrasting characteristics. The malting - feed classification affected the early development of the plants, the early - late groups responded differentially in the emergence of the flag leaf, and the two row - six row groups showed differences with regard to tillering, fertility, kernel weight and yield.

A tetraploid barley breeding program should incorporate such two row varieties as Sanalta and Golden Saitama, and also concentrate on early varieties in general. Further work on malting and feed varieties is also indicated.

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